CALIBRATION AND APPLICATION OF METEOROID/DEBRIS FAILURE PROBABILITY ASSESSMENT CODE

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ABSTRACT
Failure probability is very important in assessment to the meteoroid/debris impact risks. The framework of the meteoroid/debris failure probability assessment code, MODAOST is introduced in this paper, and the validity of the code was calibrated under the standard test cases of IADC. At last, an example assessment of the spacecraft is presented.

KEYWORDS
Spacecraft
Space debris
Failure Probability
Risk Assessment
MODAOST

1. PREFACE

Since the launch of Sputnik-1 on 4 October 1957, there have been more than 4000 satellites being placed in orbit. For each satellite launched, several other objects are also injected into orbit, including rocket upper stages, instrument covers, etc. Accidental, and sometimes deliberate, collisions between or explosions of such objects have created a very large number of fragments of varying sizes over the years. And that, there are many meteoroids in the neighbourhood of the Earth. High-velocity impacts of meteoroid and orbital debris (M/OD) threaten the safety operation of the long life and large size spacecraft, which can in turn lead to significant damage and catastrophic failure of spacecraft.

In order to assess M/OD impact risks of the spacecraft, a risk assessment code has been developed from the end of 2002 by CAST. In this paper, the framework of the assessment tool, MODAOST is introduced, and the validity of the code is calibrated under the standard test cases of IADC. At last, an example assessment of the spacecraft is presented.

2. DEVELOPMENT OF CODE

MODAOST consists of platform, application module and pre-post module. The platform and pre-post module are provided to MODAOST under secondary development of PATRAN, and the impact probability and failure probability code are integrated into the applied module. The framework of M/OD failure probability assessment code is presented in Fig. 1.

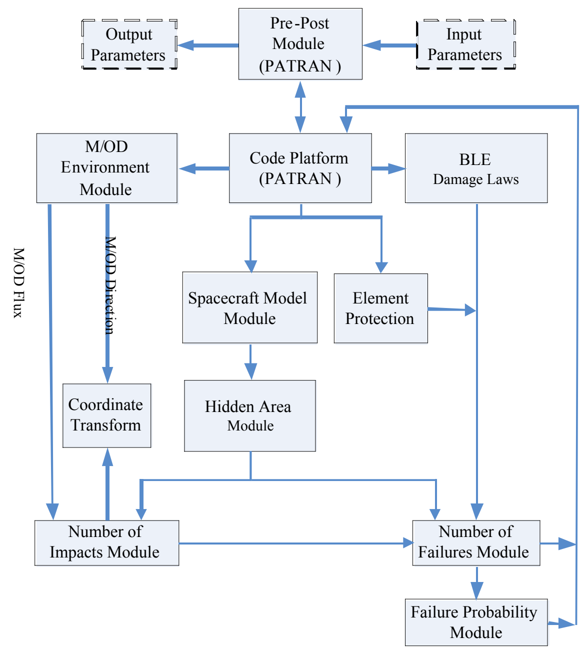

Figure 1 framework of the code

3. VALIDATION OF CODE

3.1.Definition of Calibration Runs

(1)IADC Calibration Cases
Three spacecraft geometries were defined for the validation of the M/OD failure probability assessment code:

- a simple box (Fig. 2) with edge length of 1m;
- a sphere with 1 square meter cross section (Fig. 3) with 1m^2 cross-sectional area and 1.1284m diameter;
- a simple space station (Fig. 4) with 1m edge length of the cubical box #1, 1m diameter of all cylindrical modules, 1m long of Cylinders #2 and #4, 2m long of cylinder #5, 2m long of cylinder #3.

(2)Environment Models and Mission Parameters

The environment models to be applied are:

- NASA debris '91
- ORDEM2000
- Meteoroid model (i.e. NASA SSP-30425, Rev.B, for BUMPER; Grün model for ESABASE; NASA SSP-30425, Rev.A, for MODAOST and MDPANTO)

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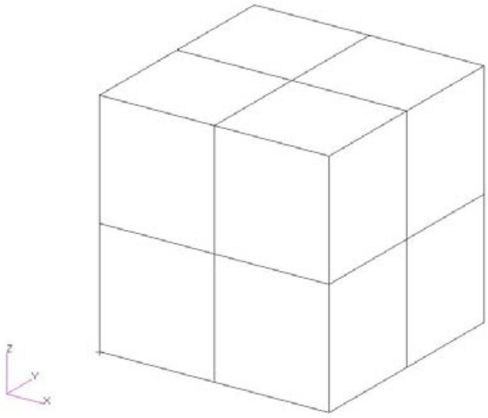

Figure 2 Geometry of the Box

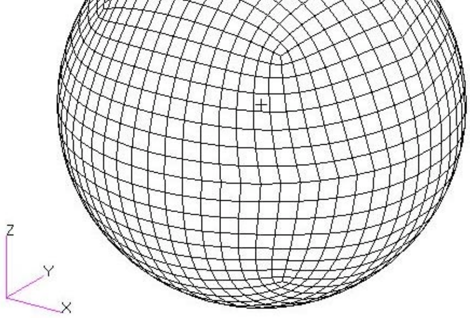

Figure 3 Geometry of the Sphere

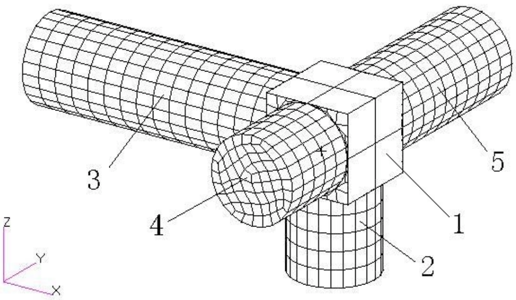

Figure 4 Geometry of the simple Space-Station

The environment/mission parameters are:

- Altitude = 400 km; Inclination = 51.6 deg; Launch 2002, 1 year duration
- NASA '91: S=70, p=0.05, q=0.02
- meteoroid density = 1g/cm^3 (for all particle masses)
- debris density = 2.8 g/cm^3

(3)Ballistic Limit Equations and Material Properties

Ballistic limit equation to be used:

- Single wall and Whipple shield equations given in Christiansen, 1993.

Material properties for Al 6061-T6 single wall and first layer in double wall structure:

- brinell hardness = 95,
- density = 2.713 g/cm^3,
- speed of sound = 5.1 km/s

Material properties for rear wall in double wall structure (Al 2024-T3):

- yield strength = 47 ksi

(4)Desired Output of the Calibration Runs

For each geometry, five runs are defined in order to investigate its behaviour in the M/OD-environment:

- number of impacts by particles with d $\geq$ 0.1 mm
- number of impacts by particles with d $\geq$ 1.0 cm
- number of impacts resulting in craters with depth p $\geq$ 1.0 mm
- "Single": number of penetration in single wall structure: 1mm wall thickness
- "Double": number of penetration in double wall structure: 2mm shield thickness, 4 mm backwall thickness, 10 cm spacing

3.2.Calibration Results

Calibration runs were performed by CAST, using the M/OD failure probability assessment code. A summary of available results are presented in Tab. 1 for the cube, in Tab. 2 for the Sphere, and in Tab. 3 for the Space Station. More detailed calibration results for each face of the cube between MDPANTO and MODAOST are presented in Tab. 4. Distribution for number of penetrations per area are presented in Fig. 5, Fig.6 and Fig. 7.

Table 1 Number of impacts/penetrations for the cube

	cm	BUMPER	ESABASE	MDPANTO	MODAOST	_1(%)	_2(%)	_3(%)
NASA 91	d ≥ .01	4.464E+00	4.560E+00	4.473E+00	4.473E+00	0.2	1.9	0
	d ≥ 1.0	5.689E-05	6.200E-05	5.702E-05	5.702E-05	0.2	8.0	0
	p ≥ .01	8.218E-02	8.900E-02	8.094E-02	8.144E-02	0.9	8.5	0.6
	single	3.307E-01	3.600E-01	3.256E-01	3.276E-01	0.9	9.0	0.6
	double	2.052E-04	2.100E-04	2.034E-04	2.057E-04	0.2	2.0	1.1
ORDEM 2000	d ≥ .01	2.126E+01	\	\	2.129E+01	0.1	\	\
	d ≥ 1.0	2.875E-06	\	\	2.878E-06	0.1	\	\
	p ≥ .01	3.520E-01	\	\	3.343E-01	5.0	\	\
	single	1.711E+00	\	\	1.627E+00	4.9	\	\
	double	2.366E-05	\	\	2.650E-05/1.524E-05	12.0/35	\	\
Meteoroid	d ≥ .01	1.201E+01	2.120E+01	2.164E+01	1.088E+01/2.014E+01	9.4/67.7	5.0	6.9
	d ≥ 1.0	3.510E-06	1.300E-06	1.360E-06	3.181E-06/1.267E-06	9.4/63.9	2.5	6.8
	p ≥ .01	1.013E-01	8.300E-02	9.064E-02	9.079E-02	10.4	9.4	0.2
	single	6.797E-01	6.000E-01	6.204E-01	6.161E-01	9.4	1.0	0.7
	double	3.154E-05	1.200E-05	1.142E-05	3.529E-05/1.192E-05	11.9/62	0.7	4.4

Table 2 Number of impacts/penetrations for the sphere

	cm	BUMPER	ESABASE	MDPANTO	MODAOST	_1(%)	_2(%)	_3(%)
NASA 91	d ≥ .01	3.288E+00	\	3.302E+00	3.318E+00	0.9	\	0.5
	d ≥ 1.0	4.191E-05	\	4.209E-05	4.230E-05	0.9	\	0.5
	p ≥ .01	5.518E-02	\	5.355E-02	5.258E-02	4.7	\	1.8
	single	2.220E-01	\	2.154E-01	2.115E-01	4.7	\	1.8
	double	1.425E-04	\	1.394E-04	1.417E-04	0.6	\	1.6
ORDEM 2000	d ≥ .01	1.695E+1	\	\	1.692E+1	0.2	\	\
	d ≥ 1.0	2.134E-6	\	\	2.151E-6	0.8	\	\
	p ≥ .01	2.157E-01	\	\	1.991E-01	7.7	\	\
	single	1.082E+00	\	\	9.965E-01	7.9	\	\
	double	1.554E-05	\	\	1.713E-05/1.020E-05	10.2/34	\	\
Meteoroid	d ≥ .01	8.075E+00	\	1.457E+01	7.056E+00/1.361E+01	12.6/68.5	\	6.6
	d ≥ 1.0	2.360E-06	\	9.200E-07	2.063E-06/8.563E-07	12.6/63.7	\	6.9
	p ≥ .01	6.463E-02	\	5.779E-02	5.701E-02	11.8	\	1.3
	single	4.362E-01	\	3.976E-01	3.881E-01	11.0	\	2.4
	double	1.997E-05	\	7.180E-06	2.201E-05/7.437E-06	10.2/63	\	3.6

Table 3 Number of impacts/penetrations for the simple space-station model

	cm	BUMPER	ESABASE	MDPANTO	MODAOST	_1(%)	_2(%)	_3(%)
NASA 91	d ≥ .01	1.758E+1	1.700E+01	1.761E+01	1.766E+01	0.5	3.9	0.3
	d ≥ 1.0	2.240E-04	2.300E-04	2.245E-04	2.251E-04	0.5	2.1	0.3
	p ≥ .01	2.992E-01	3.100E-01	2.920E-01	2.889E-01	3.4	6.8	1.1
	single	1.204E+00	1.240E+00	1.175E+00	1.162E+00	3.5	6.3	1.1
	double	7.837E-04	7.400E-04	7.654E-04	7.755E-04	1.0	4.8	1.3
ORDEM 2000	d ≥ .01	9.170E+01	\	\	9.149E+01	0.2	\	\
	d ≥ 1.0	1.151E-05	\	\	1.155E-05	0.3	\	\
	p ≥ .01	1.227E+00	\	\	1.116E+00	9.0	\	\
	single	6.150E+00	\	\	5.583E+00	9.2	\	\
	double	8.934E-05	\	\	9.376E-05/5.717E-05	4.9/36	\	\
Meteoroid	d ≥ .01	5.130E+01	8.960E+01	9.247E+01	4.506E+01/8.679E+01	12.2/69.2	3.1	6.1
	d ≥ 1.0	1.499E-05	5.600E-06	5.820E-06	1.317E-05/5.462E-06	12.2/63.6	2.5	6.2
	p ≥ .01	4.187E-01	3.400E-01	3.732E-01	3.729E-01	10.9	9.7	0
	single	2.819E+00	2.470E+00	2.564E+00	2.536E+00	10.0	2.7	1.1
	double	1.297E-04	4.900E-05	4.657E-05	1.440E-04/4.865E-05	11.0/62	0.7	4.5

Note: '\'indicates no data; If there are two results in a element for number of impacts, the left result is number of impacts for single wall with variable meteoroid density (0.5g/cm^3, 1.0g/cm^3, 2.0g/cm^3), the right result is number of impacts for single wall with constant meteoroid density (1.0g/cm^3); If there are two results in a element for number of penetrations, the left result is number of penetrations for Whipple with MLI, the right result is number of penetrations for Whipple without MLI; _1,_2,_3 indicate separately the difference percent between MODAOST and BUMPER, ESABASE, MDPANTO

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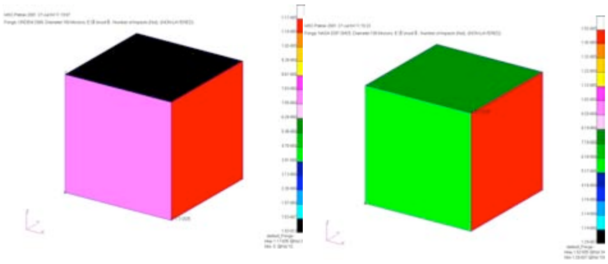
Table 4 Number of impacts/penetrations for the cube calibration

	cm	+X Face	+Y Face	-Y Face	-X Face	+Z Face	-Z Face	Total
MDPANTO								
NASA 91	d ≥ .01	2.327E+00	1.073E+00	1.073E+00	0	0	0	4.473E+00
	d ≥ 1.0	2.966E-05	1.368E-05	1.368E-05	0	0	0	5.702E-05
	p ≥ .01	5.506E-02	1.294E-02	1.294E-02	0	0	0	8.094E-02
	single	2.215E-01	5.207E-02	5.207E-02	0	0	0	3.256E-01
	double	1.198E-04	4.178E-05	4.178E-05	0	0	0	2.034E-04
Meteoroid	d ≥ .01	7.692E+00	3.626E+00	3.626E+00	9.851E-01	5.177E+00	5.313E-01	2.164E+01
	d ≥ 1.0	4.840E-07	2.282E-07	2.282E-07	6.198E-08	3.257E-07	3.343E-08	1.360E-06
	p ≥ .01	5.247E-02	1.047E-02	1.047E-02	7.178E-04	1.370E-02	1.064E-04	8.794E-02
	single	3.515E-01	7.770E-02	7.770E-02	5.938E-03	1.025E-01	5.095E-03	6.204E-01
	double	7.063E-06	1.275E-06	1.275E-06	8.077E-08	1.658E-06	7.030E-08	1.142E-05
MODAOST								
NASA 91	d ≥ .01	2.327E+00	1.073E+00	1.073E+00	0	0	0	4.473E+00
	d ≥ 1.0	2.966E-05	1.368E-05	1.368E-05	0	0	0	5.702E-05
	p ≥ .01	5.568E-02	1.288E-02	1.288E-02	0	0	0	8.136E-02
	single	2.243E-01	5.168E-02	5.168E-02	0	0	0	3.264E-01
	double	1.213E-04	4.221E-05	4.221E-05	0	0	0	2.057E-04
Meteoroid	d ≥ .01	5.783E+00	3.502E+00	3.499E+00	1.615E+00	5.408E+00	3.298E-01	2.014E+01
	d ≥ 1.0	3.639E-07	2.204E-07	2.202E-07	1.016E-07	3.404E-07	2.076E-08	1.267E-06
	p ≥ .01	4.159E-02	1.341E-02	1.340E-02	1.692E-03	1.893E-02	5.931E-05	8.908E-02
	single	2.754E-01	9.291E-02	9.283E-02	1.267E-02	1.317E-01	4.715E-04	6.060E-01
	double	5.686E-06	1.679E-06	1.678E-06	1.852E-07	2.352E-06	4.714E-08	1.163E-05

For number of impacts, the difference between MODAOST and BUMPER is below 1 percent, as between MODAOST and MDPANTO. The difference between MODAOST and ESABASE is basically below 5 percent, only the difference of one case (d ≥ 1.0, NASA 91) is below 8 percent, but, in the same way, the difference between ESABASE and BUMPER is below 8 percent, as between ESABASE and MDPANTO.

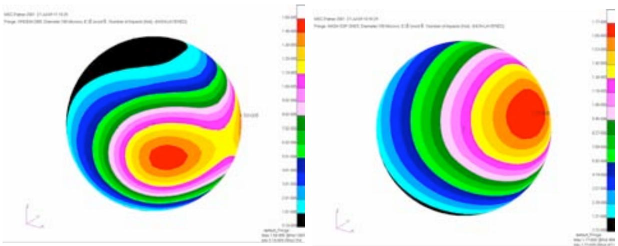
For number of penetrations, the difference between MODAOST and BUMPER is below 12 percent, below 5 percent between MODAOST and MDPANTO, below 10 percent between MODAOST and ESABASE. But, the difference among ESABASE, BUMPER and MDPANTO is almost up to 8 percent.

Distribution is consistent in orbital debris number of impacts/penetrations between MODAOST and MDPANTO. However, the difference for meteoroid number of impacts/penetrations is great, which may result from different ways of processing velocity effect.



ORDEM2000 Meteoroid model

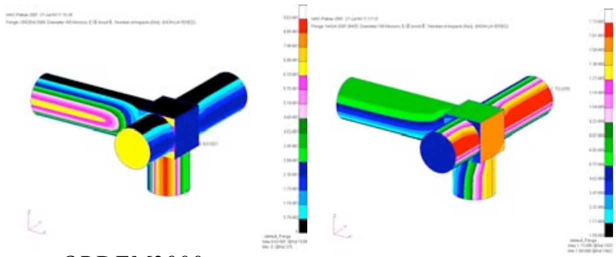
Figure 5 Distribution for number of Whipple penetrations per area for the cube



ORDEM2000

Meteoroid model

Figure 6 Distribution for number of Whipple penetrations per area for the sphere



ORDEM2000

Meteoroid model

Figure 7 Distribution for number of Whipple penetrations per area for the simple space-station model

5. CONCLUSION

The M/OD assessment and optimization system tool, MODAOST had been developed independently in CAST. The validity of the code had been calibrated under the standard test cases of IADC, calibration results between MODAOST and the other codes are presented. Now, the code of protection design optimization is in development.

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